EXPLORING THE CONSEQUENCES OF 4D BIM INNOVATION ADOPTION

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UK Government has ambitions for improvements in construction project time predictability. Better management of construction innovations into use could help with this aspiration, but despite a recent drive advocating Building Information Modelling (BIM) innovation adoption, the construction industry is still perceived to have low innovation levels in comparison with other sectors. The purpose of the work was to explore the use and consequence of 4D BIM innovation in relation to construction time predictability. Insights were gained using semi-structured telephone interviews conducted with a range of construction practitioners. Several dimensions of consequences of 4D BIM innovation adoption were considered including desirable/ undesirable consequences, direct/indirect consequences and anticipated/unanticipated consequences. In addition to consideration of the benefits and demand for 4D BIM, the results also reveal criticisms over current planning mediums and process inefficiencies. Results also reveal concerns over the additional work required to create 4D plans, and the quality of the plans produced.

Keywords: 4D planning, Building Information Modelling, BIM, innovation diffusion

INTRODUCTION

A 2013 UK Government strategy report (HM Government, 2013) outlined a ‘Vision for 2025’ for six key aspirations including construction project time performance. By 2025 this is targeted to be 50% faster than the 2013 performance, with measurement achieved through ‘time predictability’ key performance indicators (KPIs). Whilst it can be argued that improvements in construction time predictability and reductions in construction time are distinct and should be disentangled, the use of 4D BIM is considered a useful addition to the construction planning process that can help realise these dual Government ambitions. 4D BIM is where a 3D-model incorporates the fourth time dimension in order to simulate and rehearse planned construction sequences.

Key benefits of the application of 4D planning involve the reduction of uncertainty from the planning process. Previous quantitative research presented at the 31st ARCOM conference reported on an investigation into the diffusion of 4D BIM as an innovation, and an increasing rate of adoption was found with the typical time lag between awareness and first use revealed as being between 1.75 – 3.00 years (Gledson, 2015). As part of a wider PhD project, concurrent qualitative data was also collected to support the findings of the quantitative research. In particular the aim of this research was to further explore and predict the consequences of 4D BIM innovation adoption, and to ultimately consider if the use of 4D BIM can help improve the time predictability of construction projects in

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order to improve certainty and therefore speed. This paper presents summary results of some of the qualitative data gathered.

4D BIM as an innovation

An innovation is defined as "*an idea, practice or object that is perceived as new by an individual or other unit of adoption*" (Rogers, 2003). Though innovations may offer improvements, many researchers (Demian and Walters, 2014; Gambatese and Hallowell, 2011; Koskela and Vrijhoef, 2001; Slaughter, 1998) believe that the industry suffers from low rates of innovation generation and absorption. Innovations have been classified into five separate innovation types by with researchers (Koskela and Vrijhoef, 2001; Reichstein *et al*., 2005) arguing that the most frequent innovation types in construction are *incremental* or *modular* in nature, and are usually product, rather than process-based generated by suppliers, because of difficulties in implementing innovations that require larger scale systematic change. The structure and project based nature of the industry have both been identified as affecting the rate of industry innovation adoption (Dubois and Gadde, 2002; Emmitt, 2010; Harty, 2005; Taylor *et al*., 2004; Winch, 2003) and Walker (2016) argues that "*effective innovation requires an understanding of the context in which the innovation came about, the way that it may be adapted or replicated in future and the implications of this on creating value for an enterprise or organization*".

Despite having its origins in the late 1980s through the work of Marin Fischer and associates from Stanford University, 4D BIM as an innovation has recently come to prominence partly because of the targeted improvements in construction project time predictability (HM Government, 2013), and because industry practitioners have been encouraged to challenge standard planning solutions (Greenwood and Gledson, 2012). The use of Building Information Modelling (BIM) offers opportunities to enhance functions of construction planning. BIM has been categorized as an innovation (Brewer and Gajendran, 2012; Davies and Harty, 2013) that is radical, transformative and disruptive (Gledson, 2016).

The rich information contained within a BIM can be re-used for purposes such as time scheduling (Kensek, 2014) in 4D mediums that link a construction programme to a 3D-model. 4D BIM can be described as a method that allows the combination of 3D representations of the product that is to be built, with the time schedule data (and possibly a 3D representation of the surveyed existing site conditions) to virtually model the process of construction. "*Such integration, in turn, allows for three dimensional representation of when and where physical objects are planned to be built or demolished and enables co-builders to visually identify conflicts between their different work tasks and domain specific designs. This function should, in theory, support the planning activities for the above described co-creation construction efforts*" (Trebbe *et al*., 2015).

Currently, 4D BIM enhances traditional construction planning by allowing visualisation and interrogation of construction sequences (Gledson and Greenwood, 2014, 2016). Traditionally, the most frequently used communication formats for planning were bar charts produced from CPM scheduling software. Researchers have also identified that 4D BIM is able to improve communication of the construction plan by helping narrow the communication gap (Dawood, 2010; Heesom and Mahdjoubi, 2004; Liston *et al*., 2001; Mahalingam *et al*., 2010) which should, in turn reduce the '*transactional distance*' between actors (See Barrett, 2002; Moore, 1993; Soetanto *et al*., 2014).

Rogers (2003) identifies one of the main criticisms of diffusion research as a '*Pro-innovation bias'*, where, because innovation is implicitly a positive word, the bias is the assumption that an innovation should be diffused and should be adopted by members of the social system in a rapid manner.

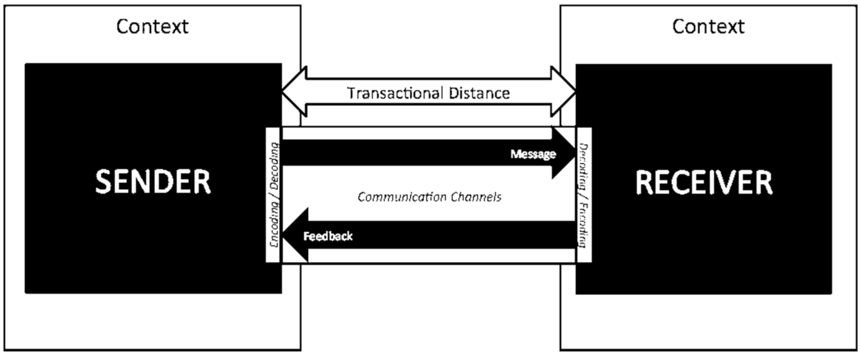

Figure 1: Transactional distance within communication processes

Consequences and the pro-innovation bias

However, there are always consequences involved in any innovation adoption, and these consequences can be negative as well as positive. Walker (2016) argues that unintended consequences require minimization and intended consequences require amplification. There is however, little research in the way of the consequences of innovations and Rogers (2003) attempts to clarify why this might be. He suggest that change agencies assume or over emphasize that all aspects of innovation will be positive; that data collection methods are usually inadequate; and the effects of consequences are not readily measured.

Rogers (2003) believed that it would be useful to analyse three dimensions of consequences:

•Desirable versus undesirable consequences

•Direct versus indirect consequences

•Anticipated versus unanticipated

In this research, during the semi-structured interviews participants were asked to consider these dimensions in relation to 4D BIM.

METHOD

Qualitative interviews were conducted concurrently while data were collected through the questionnaire survey. The questionnaire concluded by asking Participants if they would be willing to participate in a follow up interview. In total 13 participants agreed and subsequent telephone interviews were arranged. The question list was sent in advance to allow participants to more fully consider their responses in advance of the interview. Audio from all interviews was captured digitally and verbatim transcripts were produced using a word processing application. The Computer Assisted Qualitative Data Analysis Software (CAQDAS) package used earlier was used to aid the analysis of the qualitative data. Codes were pre-assigned to capture and compare the responses against each question with subsequent coding occurring during the analysis as various themes emerged.

RESULTS AND ANALYSIS

Many researchers (Demian and Walters, 2014; Gambatese and Hallowell, 2011; Koskela and Vrijhoef, 2001; Slaughter, 1998) (Slaughter, 1988; Koskela and Vrijhoef 2001; Gambatese and Hallowell, 2011; Demian and Walters, 2014) believe that the industry suffers from a low rate of innovation. Participants were asked:

What is you assessment of the level of innovation in the construction industry?

Construction was described as *"Not a highly innovative industry"* (Participant 7), there was general agreement with the literature that there was a low rate of direct innovation and that construction "*lags behind other industries*" (Participant 47). Criticism of traditional construction methods and techniques were expressed, with concerns that even though newer, safer means of performing construction work were available, low levels of such technological innovation adoption were apparent. Participants considered that typical innovation adoption in construction related to alternative or substitution materials, such as *"the likes of light fittings* [that] *have changed to LED types*" (Participant 94). These are what Slaughter (1998; 2000) referred to as *incremental innovations*, which create improvements to existing practice with minimal impacts upon the wider system. Despite this, several participants were optimistic about both recent trends in construction innovation "*it is improving [in] the last few years"* (Participant 41) and future opportunities "*there are lots of barriers in the way, but I do think it's getting there"* (Participant 56). Several of the barriers discussed related to industry structure.

Researchers have also argued that construction innovation must be considered within the context of the industry itself because of the characteristics of the industry; that it is analogous to a decentralised complex system, project based in nature, using Temporary Project Organisations (TPO) as delivery vehicles. Various researchers believe that these attributes directly affect the impact of innovations (Dubois and Gadde, 2002; Winch, 2003; Taylor and Levitt. 2004; Harty, 2005; Emmitt, 2010). Participants were asked:

Does the way the industry is structured affect the levels of construction innovation?

This question promoted particularly emphatic responses from participants "*yes, massively so*" (Participant 7) and *"I think there is a massive problem within the industry in the way that it is structured"* (Participant 95). The location-dependent and project-based nature of the industry was identified as key aspects affecting levels of innovation, *"I think there is lots more challenges than the likes of the manufacturing industries. Obviously [there is the] location of where you are building compared to being in a more static place … we are building in a different place each time … [and] … the structure, culturally is very different"* (Participant 56).

Rogers (2003) considers 'the nature of the social system', its norms, and degree of network interconnectedness, to be a key aspect when considering the diffusion of innovations. Rather than explicitly discussing industry structure, participant concerns were focused more on the norms of the construction system including aspects of fragmentation, procurement processes, the market environment and business practices whilst challenges of *culture*, *time*, and *system complexity* also featured heavily in the interviews.

Has 4D BIM impacted upon the planning of construction work?"

In terms of actual 4D BIM use some participants considered that it was used more on "*bigger and more complex jobs*" (Participant 53) and that "*for the bigger projects, [such as] Terminal 5 [etc.] it's really important*" (Participant 11). Some participants from adopter organizations noted that 4D BIM was being treated as a kind of added value service, only being provided as a specific additional service and then only if specified by the client team "*At this stage 4D BIM is dependent on the client buying into the concept; not de-facto given in our typical workflow. Still seems to need mainstream acceptance*" (Participant 184). Similarly, Participant 8 noted that his organization could provide 4D output, but were "*working purely based on demand. They are only providing it if it has been specified or clearly asked for*".

In contrast, several participants who work for early adopter organizations that had implemented 4D BIM and had used this innovation across multiple projects were able to provide numerous examples of the benefits, which included: options analysis; being able to provide the client with alternative proposals; successfully resolving logistical challenges on site; arranging early procurement of materials; and reduction of programme durations.

One flaw with the use of bar charts for communication was identified by participant 19 who also advises on one of the major strengths of 4D BIM as an innovation: *"Nobody really looks at a programme do they? No, but they would look at a* [4D] *video of how the job is going together and they would understand it … because it's visual, everyone knows what the building looks like when it goes up, and what it will look like half constructed, but if they looked at the programme they wouldn't really have that visual image in their head"*.

Participant 63 however, noted caution when identifying that, despite the communication advantages that 4D BIM innovation offers through better visualizations of the plan, the traditional lack of a feedback loop to aid communication comprehension remains. "*In terms of construction I'd say that it [4D BIM] has increased the representation and visualization aspects, but what is missing in every part of the construction, in terms of planning, is the feedback. We take things for granted so we don't challenge anything … we talk about planning construction work about how it is about sequencing, but we don't improve it, [using] feedback. We just do it and say, 'Yes, I can see the plan, that is what I am doing' but we don't challenge that. We don't optimize the process, which BIM can do by increasing the representation for all stakeholders"*.

What are the consequences of 4D BIM innovation?

Desirable and undesirable consequences

Participants articulated several desirable consequences including, the greater levels of detail in which the construction plan can be communicated, and the visualisation benefits of being able to see objects within the model being virtually constructed in alignment with the agreed construction sequence.

Other participants however viewed additional work content created as one of the undesirable consequences. *"I describe 4D BIM as a managers dream and a planners' nightmare. For the manager he can go into depth … [and] then decide whether he likes it or not and if something needs changing. It's a planners' nightmare because he's not just engaging with one manager… you get maybe 3 or 4 managers input which means that the programme is constantly getting more and more input, until you manage to hit something which in theory is good enough to be construction issue"* (Participant 7).

Participants generally see increased levels of client involvement as an undesirable consequence that will generate dysfunctional conflict. However, despite these concerns, the experiences of Participant 48 suggest that construction actors will continue to fulfil traditional roles regardless of the opportunities provided by 4D BIM innovation *"I would* *say so far we have had very little interrogation of our programmes at all and anything 4D that we have done. It purely seems to be viewed as a visual tool by the client and a pretty picture".*

Direct and indirect consequences

Several participants discussed the direct consequences in relation to the benefits of 4D BIM addressed elsewhere in this work. Participant 41 however, articulated the rapid diffusion of this innovation in work winning environments as a direct consequence, *"I suppose the best thing is the take up of it and almost the fact that it is expected to be used during work winning now".*

Indirect consequences related to being able to prove the benefits in order to justify use. The challenges of being able to quantify such outcomes were something considered by Participant 8 *"We are not at the stage of being able to measure benefits of it … I would say that once we have completed that learning curve, then we can start measuring output data and see if our output data has improved against our traditional output data".*

Participant 41 also suggested that the quality of the construction plan might be inferior to current methods used. "*There is an argument to say that when you hand drew a programme, before you committed it to paper, you were bloody sure that it was right… because the consequences of having to alter it, were laborious. Whereas now, people can just quickly knock up a bar chart, print it off, issue it, and not worry about if it is as accurate as it could be".*

Anticipated and unanticipated consequences

Most participants however, believed that programme quality would increase as a result of the adoption of 4D BIM innovation particularly in terms of planning and sequencing the work, *"It has highlighted quite a few [incorrect] things within my logic that I have used on several jobs in that past and it has bettered my programmes and made them more workable"* (Participant 53).

Negative anticipated consequences were that contractors might lose out on available work as *"you would have more idea of what temporary works was needed by having 4D BIM … it might help with the pricing, but also you might put too much [money] in and possibly price yourself out"* (Participant 47).

Unanticipated consequences included aspects of process:

> It has highlighted the culture I suppose, it has highlighted the way we do, the way we approach things … general working practices. Without being able to observe 4D BIM innovation, I suppose I wouldn't have identified this lack of feedback … I wouldn't readily have identified that, so it has allowed us to understand the problems that little bit better (Participant 63).

… and the current rate of diffusion:

> There is definitely a demand there from the work winning side of things and we are having to move forward in order to delivery that really … It's been noticeable, it seems to be increasing pace all the time (Participant 41).

Do you think the use of 4D BIM can help improve the time predictability of construction projects?

Participants generally believe that some level of improvement to construction project time predictability can be achieved with the use of 4D BIM. *"4D allows you to be more accurate in your estimations, planning wise. It's better visually, people clearly understand it and grab the concepts and actually see what need to be done first rather than trying to work through a Gantt chart"* (Participant 11).

Participant 8 argued the need for more reliable information to be available for the planning of construction activities and task durations in order for this increased level of accuracy to be realised. This participant identified that this could be achieved through the future capture of actual performance data and the re-use of this information to determine future task durations. *"I think, being able to feed output data back into the cloud would be a big help … being able to record your actual progress and then feed your actual progress back … download that data to your next program, should give you greater certainty in your durations"*.

Participants usually considered that predictability improvements could be gained by also altering other aspects of the project delivery process, such as increasing off-site periods in order to reduce on site periods. *"[For] time on site, I would say yes, the time overall from inception, I would say no. I think, [that] the time they spend producing models in the first place and the information within the models [will help]"* (Participant 53). Optimising project tendering and procurement practices to enable earlier involvement by constructors was also considered. *"I think using 4D BIM innovation in the design process phase … to visualise [the construction process] we would be able to improve, understand and optimise, potentially from the 'strategic definition' stage, however that is hindered by your typical procurement [arrangements] in terms of sequencing appointments"* (Participant 63).

The use of 4D BIM innovation in conjunction with greater use of other construction innovations such as pre-fabrication and modern methods of construction (MMC) was considered to be a more pragmatic method of improving construction project time predictability. *"I think it can help improve time predictability, but I'm not sure it can do it to the point where projects will be delivered 50% faster, certainly not on its own. I think the only way you [are] going to get it that much faster, is if you massively increase [the use of] offsite construction"* (Participant 8). In contrast, Participant 7 who has extensive use of 4D BIM innovation believed that his current project where 4D BIM is being used in conjunction with MMC whilst maximising the advantages of virtual prototyping would achieve the desired results. *"Yes I actually think the target is achievable … I believe an improvement of 50% faster is possible, certainly. From my experience with 4D in the last 5 or 6 years I definitely think its achievable, I think you may see it going even higher than that"*.

DISCUSSION

Previous related quantitative research by Gledson (2015) found an increasing rate of 4D BIM adoption with the typical time lag between awareness and first use identified as being between 1.75 – 3.00 years. The ultimate aim of this supporting qualitative research was, to determine its effect, through exploration and prediction about the consequences of this innovation. 4D BIM can be considered to be a modular technological process-based innovation and the data reveals that the structure of the sector continues to impact upon the levels and types of innovations that are successfully realised. Only innovations that prove a good fit contextually and environmentally have a chance of adoptive, adaptive or replicative success (Dubois and Gadde, 2000; Walker, 2016). In this investigation, regardless of the timing of adoption, two adopter attitudes emerged, those who had adopted and absorbed 4D-planning methods irrespective of the will of external agencies, and those who provided 4D BIM only when required to (e.g. through client demand or expectation or job scale). Several benefits were articulated and recent increases in demand for 4D BIM were noted.

The data show criticisms of current planning mediums and processes, but recognition of the likelihood that planning output created using 4D BIM methods should increase interrogation of the plan by project stakeholders by facilitating feedback loops. Increased engagement by construction team members is welcomed but additional efforts in exploring multiple alternative scenarios are a concern in terms of resource levels required to undertaking effective planning. Construction team interactions are seen as helping validate the plan resulting in increases in precision and detail that are also better communicated to the workforce with a resulting improvement in construction project time predictability and opportunities for potential time-savings. However, the prospect of input from external project stakeholders was not particularly welcomed: there was concerns that increased plan-transparency may result in negative interactions with the client team.

CONCLUSIONS

4D BIM has been proposed as an innovation that can help improve the time predictability of construction projects, which is needed to help realize current UK Government strategic aspirations. There are always consequences of innovation adoption, but to date, there has been little in the way of research about such consequences. This work contributes by addressing three dimensions of consequence of 4D BIM innovation adoption: *desirable/undesirable* consequences, *direct/indirect* consequences and *anticipated/unanticipated* consequences.

The principal consequences of 4D BIM innovation adoption are the opportunities afforded by the facilitation of feedback loops to further reduce transactional distance within plan communication; the associated potential increases in planning effort needed because of resultant additional interactions with construction team or client team members; the increases in the quality and validity of the plan produced; and an obvious client demand for this planning output experienced in front end work winning situations.

Respondents considered that while use of 4D BIM is expected to facilitate some improvements in construction project time predictability, targeted efforts across a range of other more familiar areas (such as better quality production information; allocation of appropriate pre-construction periods, and greater use of modern methods of construction) can also help address the time predictability problem. Future research efforts focusing on the capture and use of as-built performance data to prove the benefits and further justify the use of 4D BIM innovation would be welcomed.

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